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Industry 4.0 in firms, clusters and regions: the new digital imperative

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1-Introduction

Concepts such as digitalization or the internet of things, among others, are gaining momentum in business environments and also in industrial manufacturing, known as Industry 4.0 (Liao et al., 2017). Digitization, and Industry 4.0 specifically, is transforming entire businesses, companies, industries and platforms through the introduction of digital technologies and paradigms (e.g., key enabling technologies, social media, online stores, digital markets, cloud computing, Internet of Things, etc.) enticing a transformative digital disruption (Fitzgerald et al., 2014; Porter and Heppelmann, 2014, 2015; Nambisian, 2017; Teece, 2018; Autio et al., 2018; Galati and Bigliardi, 2019) that even accounts for regions, clusters (e.g. Bellandi et al., 2019; Hervas-Oliver et al., 2019) and global value chains (e.g. Kano et al., 2020; Sturgeon, 2019). Within the digital transformation, the concept of *Industry 4.0* encompasses the digitization of manufacturing, including different digital enabling technologies, such as *the Internet of Things, Additive Manufacturing, Big Data, Artificial Intelligence, Cloud Computing, Augmented and Virtual Reality, and Blockchain*, among others such as *Cibersecurity* or *3D printing*.

Taking a policymaking perspective, this technological shift is really prominent in all industrialized countries and especially in the European Union's agenda of priorities for 2019-2024[1], where the *Digital Single Market* industry-related initiative package is established with three main focuses on Artificial Intelligence, Data Strategy and Industrial Strategy. Within that industry-related initiatives, there are many digital policies such as the *Digital Innovation Hub* (DIH) action[2], that promotes one-stop shops that help companies become more competitive with regard to their business/production processes, products or services using digital

[1] https://ec.europa.eu/info/strategy/priorities-2019-2024
[2] https://ec.europa.eu/digital-single-market/en/digital-innovation-hubs

technologies, an action that complements Smart Specialization, among others. The EU support of digital transformation also complements other national initiatives such as the *Industrie 4.0* in Germany and Austria, *Digital Hub* program in Germany, or the *Catapult* program in UK. Policies and practices of major national and supranational governments are increasingly emphasizing the relevance of digitization, especially for manufacturing (Sung, 2018; Li, 2018). As Galati and Bigliardi (2019) point out, Industry 4.0 is widely debated across several academic disciplines and perspectives, such as business, human resources or skills, sustainability or operations and technology, the latter in a very intense way due to its own nature. All industrialized countries have started national programs aimed at developing a proper regulatory framework from which to facilitate the development of Industry 4.0. Starting with Asia, South Korea in 2014 launched its "Innovation of manufacturing 3.0" (Kang et al., 2016). Subsequently, China did the same with its "Made in China 2025" program and the "Super Smart Society" plan of Japan in 2015 (see more at Li, 2018). Similarly, Italy has established the *Piano Industria 4.0*, Portugal the *i4.0* program, Spain the *Industria Conectada 4.0* and Austria the *Industrie 4.0* among other national programs oriented to digitize manufacturing.

Despite these emergent policy programs at different spatial-levels and the pioneering efforts on developing conceptualizations and logics of *Industry 4.0* from the management, economics, and business community (e.g. Nambisian, 2017; Müller et al., 2018), its application to firms' innovation and competitiveness, its logics, theorizing, empirics and real application are nascent as regards R&D projects (e.g. Muscio and Ciffolilli 2020), business models, (e.g. Müller et al., 2018; Frank et al., 2019a; Müller et al., 2019), sustainability (e.g. Ghobakhloo, 2020), technologies (Frank et al., 2019b), global value chains (e.g. Kano et al., 2020; Lee et al., 2020; De Marchi et al., 2020) or addressing emergent literature reviews of the phenomenon (e.g. Oztemel & Gursev, 2020). As such, theory, frameworks and empirics are being developed at the present time and gaining momentum, albeit the literature is not prolific yet. The phenomenon, therefore, constitutes an emerging research gap in the study of firms from a managerial and innovation perspective that spans firms, industries and places. In this chain of thought, several interesting questions arise: how does Industry 4.0 affect firms' competitiveness and innovation? What are the facilitators or barriers to adopting Industry 4.0? Similarly, addressing place and economic geography, the study of Industry 4.0 in clusters and regions is nascent with some pioneering contributions addressing clusters innovation and policymaking (e.g. Götz and Jankowska, 2018; Hervas-Oliver et al., 2019; Bellandi et al., 2019; Sturgeon, 2019; De Propris and Bayley, 2020). From this perspective, different research

questions are posed: how does Industry 4.0 shape industrial clusters and regions? What are the fundamental policy initiatives promoting Industry 4.0 adoption in firms, clusters and regions? To what extent does Industry 4.0 impact differently regions? All these questions and many more bring interesting challenges to the conversation that contributors in this Special Issue address.

All in all, this Special Issue attempts to provide a cross-fertilization of different literatures and perspectives, integrating firm innovation, competitiveness and clusters/regional literature (e.g. Porter, 1998; Hervas-Oliver and Albors-Garrigos, 2007; Hervas-Oliver and Albors-Garrigos, 2009; Eisengerich et al., 2010; Funk, 2014; Hervas-Oliver et al., 2017; Giuliani et al., 2018) with digitization and Industry 4.0 (e.g. Porter and Heppelmann, 2014; 2015; Nambisan, 2017; Teece, 2018; Autio et al., 2018; Müller et al., 2019; Bettiol, Di Maria and Micelli, 2020). This special issue's purpose is to adopt a broad managerial perspective that includes the study of the phenomenon from a knowledge transfer, managerial, innovation, entrepreneurship and regional competitiveness multidisciplinary approach, emphasizing cooperation, competition and coopetition at the micro- and meso-level. Industrial clusters are, for this purpose, defined as by Porter, as "*geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (for example, universities, standards agencies, and trade associations) in particular fields that compete but also co-operate" (Porter, 1998, p. 197),* but also extending the scope to other agglomeration forms such as Marshallian Industrial Districts (e.g. Becattini, 1990; Belussi and Sedita, 2009; Hervas-Oliver and Albors-Garrigós, 2014; Hervas-Oliver et al., 2017) or innovation and entrepreneurial ecosystems (Sorenson, 2017; 2018; Autio et al., 2018). Firms, clusters and regions are all inclusive topics related to Industry 4.0 that are, theoretically and empirically, covered in this Special Issue.

To summarise, further theoretical and empirical research is needed to illuminate the intricate relationship between Industry 4.0 and digital transformation and innovation and competitiveness in firms, industrial clusters and regions. This special issue is aimed at advancing our knowledge on the topic by encouraging multidisciplinary research that develops new frameworks and theories from which to benefit scholars, innovation practitioners, cluster managers, regional planning officials, policymakers and entrepreneurs alike.

After this introduction, Section Two presents a framework from which to address Industry 4.0. Then, Section Three presents the different papers selected.

2. A preliminary framework about Industry 4.0: conceptualizing

The discussion on Industry 4.0 technologies has stressed the revolutionary dimension of such innovation by connecting technology adoption with a paradigm shift in the organization of production and value creation. The fourth industrial revolution (Schwab, 2017) leverages on a wide range of technologies included within the Industry 4.0 spectrum to promise a shift in the strategies, processes and practices through which firms serve their market, compete and innovate. Compared to the previous industrial revolution, the competitive landscape potentially designed by technologies such as automation, Internet of Things (IoT) or artificial intelligence is characterized by higher levels of connectivity among processes and actors (Almada-Lobo, 2016). Moreover, firms can redesign their business models in order to provide their value toward the customers differently, mainly within the framework of *servitization* (Iansiti & Lakhani, 2014; Kohtamäki, Parida, Patel, & Gebauer, 2020).

Studies on Industry 4.0 have heavily emphasized opportunities and impacts at the manufacturing level, where technologies related to automation and, more in general, cyber-physical systems (Zheng et al., 2018) allow a redesign of processes towards the *smart factory*. Efficiency coupled with customization and traceability with respect to the customers – i.e. through IoT – expand the potentialities of manufacturing companies of different size, where large firms may also enhance their capabilities of shaping their offering, by also involving customers. This leads to multiple relevant directions in the rise of a new competitive paradigm. Through Industry 4.0 technologies, *innovation* may further be expanded within an open innovation framework, with a central role of customers in the process (Holmström, Holweg, Khajavi, & Partanen, 2016). Following the perspective of user-driven innovation (von Hippel, 2005), customers become makers (Anderson, 2012) and can actively be part of the process of product production beyond the idea generation phase. Technologies such as 3D printing have transferred to clients the possibility of becoming producers themselves, asking for the *definition of new forms of division of labour between actors* within the value chain (Candi & Beltagui, 2018; Rayna & Striukova, 2016). The manufacturing activity becomes a blurred process between firms and customers where, on the one hand, customers may complement or substitute manufacturers and, on the other hand, firms may rely on additive manufacturing at the customer's workplace to provide additional services (Kalva, 2015). By enhancing mass

production, advanced customization becomes possible also through tailored products obtained with the investments in automation. Advanced robotics are flexible and can translate customers' inputs into adapted production activities and small-scale productions (Frank, Dalenogare, & Ayala, 2019).

Directly connected with the previous issue, industry 4.0 technologies further are overcoming the spatial boundaries and limitations, pushing forward the concept of *proximity* within the *geographical scale* of economic activities (Boschma, 2005; Laplume, Petersen, & Pearce, 2016). Based on new technologies such 3D printing, scholars have emphasized how firms may redesign their location strategies putting together manufacturing and distribution in the same place and re-organize their value chains. Reshoring phenomena and more flat smiling curves may emerge, due to the investments of industry 4.0 technologies by firms located in advanced countries (Ancarani & Di Mauro, 2018; Rehnberg & Ponte, 2018). The opportunity to gain from such technologies to reduce time-to-market and increase proximity with (advanced) customers is still considered a potential benefit of Industry 4.0 technologies, with limited research that empirically explores these trends. Further empirical research is required to provide evidence of the promising scenario the emerging technological landscape is offering, i.e. re-connecting multiple regions and firms aiming at giving value to the different specializations and capabilities, where new forms of *governances* have also to be considered (Ben-Ner & Siemsen, 2017; Hannibal & Knight, 2018; Strange & Zucchella, 2017). Not only may lead firms organize their manufacturing activities differently within their value chain, but also small firms in advanced countries may leverage on such technologies to enhance their competitiveness.

The debate on the potential revolutionary inputs of Industry 4.0 on the competitiveness of firms, regions, and local systems has also included the powerful dimension of *data management and its support for strategies*. Within the Industry 4.0 technologies, in particular Artificial Intelligence (AI) and its application on big data – collected through IoT and available through the cloud – are considered breakthrough technologies able to leapfrog the firm's ability to understand and forecast markets and, more in general, the competitive scenario (Davenport, 2018). Through such data-driven technologies the knowledge management process of firms is strongly enhanced (Bettiol et al., 2020). There is an open debate in the literature on the impacts of AI on society in general (Tegmark, 2017; Zuboff, 2019) and in the management of firms in particular. AI has the potential to change how decisions are framed and made within a firm(Shrestha, Ben-Menahem, & von Krogh, 2019). This debate is not entirely new and goes back to the 1980s and 1990s at the time of the application of the expert systems (Davenport,

2018). The difference is that today AI is more powerful in terms of computational capabilities and there is greater availability of data. In several areas such as voice recognition, image recognition and language translation, the progress of AI is relevant and has led to the deployment of very powerful solutions that are used by millions of customers. Many of the reflections on AI are based on the assumptions that such technology will question human intelligence. However, the literature on knowledge management (Pauleen, 2017; Pauleen and Wang, 2017) warned that gathering bigger data does not necessarily lead to more knowledge because knowledge is the outcome of sensemaking and human judgment. The fact the data are relatively abundant does not necessarily provide better solutions, as several negative case studies (as reported in Fry, 2018) confirm. As the philosopher Luciano Floridi pointed out (2016), AI is rather a divorce between intelligence and agency. In Floridi's words AI dramatically increased its capability of action in the real world but this has happened without increasing its intelligence, in the sense of its capability of understanding the context of action. AI introduces new agents that we have to deal with in the digital era and that will complement rather than substitute human decision making. How this will change the way firms are managed and interact among each other, is still an open question.

3. The Special Issue

This Special Issue includes eight papers that address the digitization of firms, clusters and regions. Scholars from different countries such as Spain, Italy, Poland, Germany, Austria, Norway and UK participated in this review process that was aimed at providing a high-quality and up-to-date set of studies with which to understand much better the Industry 4.0 phenomenon. Starting with more than 20 papers, the final selection shows a comprehensive and diverse array of thought-provoking contributions developed through theoretical, qualitative and quantitative lenses. Herein you'll find short presentation of them.

Starting with the paper by *Bettiol, Capestro, De Marchi, Di Maria, and Sedita* entitled "Industrial districts and the fourth industrial revolution", it analyses the relationship among the potentialities of the fourth industrial revolution, the impacts of Industry 4.0 technologies on manufacturing activities and the industrial district model. Through a mixed method the paper combines an empirical quantitative analysis on Italian firms and a case study of a district firm located in a traditional manufacturing cluster (Riviera del Brenta, luxury shoes), to evaluate to what extent the technological adoption by cluster firms is a disruptive process or more in line

with the cluster model. The authors compare district and non-district firms highlighting how Industry 4.0 technologies further support the peculiarities of the district model and the opportunities for manufacturing district firms to leverage on such technologies to push forward flexibility and customization.

By adopting a broader perspective, within the same empirical context of Italy, the paper by *Pagano, Carloni, Galvani and Bocconcelli* entitled "The dissemination mechanisms of Industry 4.0 knowledge in traditional industrial districts: evidence from Italy" is included in the theoretical debate focused on knowledge dynamics within clusters and aims at considering the factors within clusters supporting knowledge diffusion related to Industry 4.0 technologies. The empirical analysis refers to the Pesaro industrial district in Italy specializing in the furniture and woodworking machinery sector. Specifically, the paper contributes to disentangling knowledge flows connected to the adoption of Industry 4.0 technologies and the role of multiple actors (lead firms, associations, universities, local institutions) within clusters in those dynamics, adopting the perspective of traditional industries. Empirical evidence rooted on deep qualitative analysis within the Pesaro cluster outlines three main sequential evolving patterns, where the cluster progressively upgrades.

The context of cluster with its institutions characterizes also the paper by Götz on "*Cluster role in industry 4.0 – a pilot study from Germany*", which explores the role of cluster in the adoption of Industry 4.0 technologies by focusing on 36 German clusters identified through the EU cluster platform. The aim of the paper is to outline how the cluster as specific socio-economic and institutional context may facilitate and enhance the implementation of such emerging technologies being a favorable environment for innovation and policy implementation. Within a quantitative analysis on the structure and characteristics of the clusters considered, the author has carried out a survey on German clusters, targeting cluster organizations to investigate the research questions. Results show the positive role of the cluster where cooperation and competition may sustain Industry 4.0 adoption within a proactive institutional setting and where cluster organizations may represent the interface between firms and policymakers.

From Germany, the paper by *Grashof, Kopka, Wessendorf* and Fornahl on "Industry 4.0 and clusters: complementaries or substitutes in firms' knowledge creation" explores the knowledge consequences of the adoption of Internet of Things (IoT) technologies, through an extensive quantitative analysis on more than 8,300 firms in Germany and focused on patents to capture Industry 4.0 investments. The authors adopt the cluster theoretical framework to investigate

how being in a cluster impacts on the firm's innovation performances rooted in the adoption of Advanced Manufacturing Technologies (AMT), considering both incremental and radical innovation. Leveraging on studies on clusters suggesting the role of internal and external cluster connections in supporting innovation within clusters, the empirical research also includes such moderating variables in the analysis. The results achieved show a mixed scenario in terms of AMT impacts on innovation, while cluster embeddedness may partially be relevant but only for incremental innovation. This analysis further enriches the theoretical debate on cluster digitalization dynamics and opens new future research trajectories.

At the regional level, and investigating the European Digital Strategy, the paper by *Hervas-Oliver, Gonzalez-Alcaide, Rojas-Alvarado, and Monto-Mompo* entitled "Emerging regional innovation policies for industry 4.0: analyzing the digital innovation hub program in European regions" aims at exploring the characteristics of regional innovation policies that, at the European level, are developing to promote Industry 4.0 technologies. Specifically, the authors consider Digital Innovation Hubs (DIHs) as the visible and relevant element of such policies in the RIS context, where the empirical analysis is based on deep qualitative research carried out on 10 DIHs in Spain. The authors focus attention on the multi-actor perspective and on the multi-scalar institutional environment characterizing RIS that may enable the diffusion of Industry 4.0 technologies in the regions, rooted on DIHs. The paper shows the different process of adaptation of DIH to the variety of contexts by policymakers, where co-design and co-participation are fundamental processes for effective DIH supports to digitalization of SMEs. Not only raising awareness of the potentialities of Industry 4.0, but also of institutional-industry cognitive alignments and valorization of RIS and place-based features as a way to successfully deploy Industry 4.0 policies within RIS.

The paper by *Isaksen, Trippl, Kyllingstad and Rypestøl* titled: "Digital transformation of regional industries through asset modification" focusses on the role of digitalization in the definition of new trajectories of development for regions and clusters. Through an original theoretical framework, the authors introduce the concept of asset modification as an important level of analysis for understanding how digital technologies could foster the competitiveness of regions and clusters. In particular, the authors applied their framework to three case-studies of regions where digital technologies helped to revamp competitiveness through the modification of assets intended as a sum of knowledge, rules, buildings and skills embedded at the local level and historically determined. Three different forms of asset modification are identified: (1) re-use of existing assets (recycling, new use and recombination of existing

assets); (2) creation of new assets; and, (3) destruction of outdated assets. The authors then analyze how digitalization could contribute to the modification of local assets. The paper aims at contributing to the literature by proposing a new framework for regional and cluster development that tries to solve the problem of the endogeneity of growth.

The following papers take a different approach on analyzing the impact of digitalization at the firm level. In particular, the paper by *Ruel, Rowlands and Esther Njoku* titled: "Digital business strategizing: the role of leadership and organizational learning" aims at understanding how a digital strategy emerges within an organization. On the basis of an extensive literature review, the main contribution of the authors is that leadership and organization learning mediate between the contextual factors that characterize the firm and the digital strategy. The model proposed by the authors aims at defining a framework that will ensure digital business strategizing maintains a fit between organizational strategy, structure, knowledge, culture and systems.

The paper by *Fernandez and Gallardo-Gallardo* deals with the application of the digital technologies in Human Resources (HR) Management with a specific focus on HR analytics. In particular, the paper titled "Tackling the HR digitalization challenge: key factors and barriers to HR analytics adoption" aims at studying how the concept of HR analytics is interpreted and what does or does not facilitate the adoption of that practice in the organization. In their literature review, the authors find that there is a lack of clarity on the interpretation of HR analytics and there is not an agreement on the objectives and the methodologies in practice. With their paper, the authors aim at proposing clearer conceptualization of HR analytics as "a set of principles and methods that address a strategic business concern that encompasses collecting, analyzing and reporting data to improve people-related decisions." Moreover, they not only identified several barriers to the adoption of HR analytics but also how organizations could overcome them in order to take advantage of that practice.

To conclude, we want to open this research avenue and gather researchers and scholars from all different disciplines (economics, business, regional science, technology management, strategy, etc.) to tackle the phenomenon through different layers and dimensions. It needs to be studied at the micro-, meso- and macro-level, understanding firms, regions and countries. Complementarily, the concept of Industry 4.0 has to be approached from theoretical, quantitative and qualitative perspectives: from single cases to the exploitation of large-scale databases and countries. It constitutes a promising research agenda.

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